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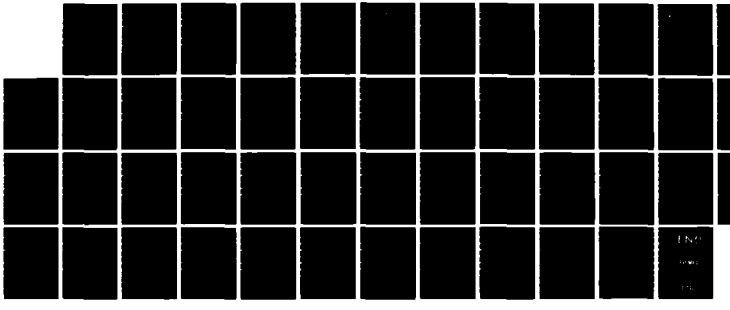

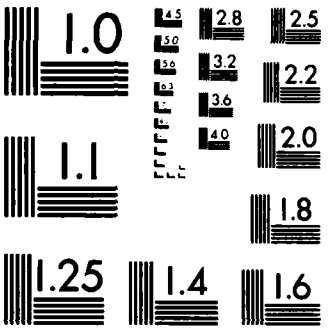

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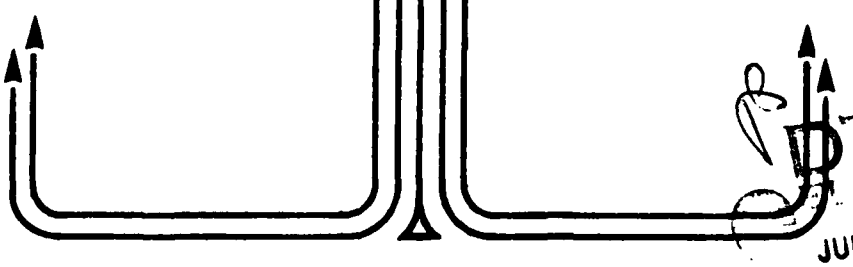
AIR COMMAND AND STAFF COLLEGE

STUDENT REPORT

CONTRACTING FOR WEAPON SYSTEM SOFTWARE:
THE PRICING ARRANGEMENT

MAJOR MICHAEL A. SPATOLA 85-2560

"insights into tomorrow"



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TITLE CONTRACTING FOR WEAPON SYSTEM SOFTWARE: THE PRICING ARRANGEMENT

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requirements for graduation.

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Software is a critical cost and performance element of weapon system acquisition. Among other problems, there has been a mismatch between software acquisition and contracts. This study reviews the procurement, acquisition, budget, and software development processes to determine the appropriate pricing arrangement for weapon system software. It concludes that either a cost-plus-fixed-fee or cost-plus-award-fee contract is appropriate for software development.

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PREFACE

Software has critical cost and performance impacts on weapon system acquisition. The reemphasis on using appropriate contract types and recent release of the Federal Acquisition Regulation offer an opportune time to address a concern that "software acquisitions and contract type [are] often mismatched". This staff analysis project determines the appropriate pricing arrangement, as described in the Federal Acquisition Regulation (FAR), for operational weapon system software.

The approach to the problem is: determine pricing arrangement uses and limitations; determine characteristics of procurement, acquisition and software development that affect pricing arrangement; and select the appropriate pricing arrangement using FAR criteria. This project is sponsored by the Ballistic Missile Office (BMO). Specific BMO program examples that support study findings are in appendices.

The author wishes to acknowledge the following people: Ms. Willoughby J. Rau, BMO/PMSA, for her support, assistance, and sponsorship of this work; Major Thomas G. Jones, ACSC/EDCM, for his critical review of this effort as the project advisor which made the project and this report better; and Majors Buddy B. Wood and Sherry D. Sims for their technical review and comment.

ABOUT THE AUTHOR

Major Michael A. Spatola graduated from the United States Air Force Academy in 1971 with a Bachelor of Science degree in Mathematics. He also holds graduate degrees from Colorado State University in Mathematics (Master of Science), from the University of Southern California in Systems Management (Master of Science), and from Webster University in Procurement Management (Master of Arts). Major Spatola's initial assignment following graduate school in 1972 was at the Foreign Technology Division as an ICBM trajectory analyst. He then spent one year at the C. S. Draper Laboratory in Cambridge, Massachusetts as an assistant to staff scientists under AFIT's Education With Industry program. Following his assignment at Draper, Major Spatola spent five years at the Ballistic Missile Office (BMO), Norton AFB, California. At BMO, Major Spatola was the Chief, MX Software Development Branch. He was also the Minuteman command and control software manager during its last program updates. As the computer resources focal point at BMO, Major Spatola received a Certificate of Excellence from the Air Force Systems Command Inspector General for establishing a computer resources management program that was rated "excellent". Major Spatola has given presentations on "Managing Software in the Weapon System Environment" to numerous organizations including the AIAA Computers in Aerospace III Conference. Prior to attending Air Command and Staff College, Major Spatola was stationed at the USAF Academy as an Assistant Professor in the Department of Mathematical Sciences. A distinguished graduate of Squadron Officer School, he was recently selected as an Outstanding Young Man of America for 1984.

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EXECUTIVE SUMMARY

Part of our College mission is distribution of the students' problem solving products to DoD sponsors and other interested agencies to enhance insight into contemporary, defense related issues. While the College has accepted this product as meeting academic requirements for graduation, the views and opinions expressed or implied are solely those of the author and should not be construed as carrying official sanction.

"insights into tomorrow"

REPORT NUMBER 85-2560

AUTHOR(S) MAJOR MICHAEL A. SPATOLA, USAF

TITLE CONTRACTING FOR WEAPON SYSTEM SOFTWARE: THE PRICING ARRANGEMENT

I. Purpose: To determine the appropriate contract pricing arrangement, as described in the Federal Acquisition Regulation (FAR), for the development of operational software during weapon system acquisition.

II. Problem: With an increased emphasis on using contract types that are appropriate for the specific acquisition and the recent release of the new Federal Acquisition Regulations, it is necessary to correct what some studies refer to as a "mismatch between software acquisitions and contracts".

III. Data: The FAR and laws enacted by Congress regulate the federal procurement system. The FAR describes applications and limitations for contracts. The Defense System Acquisition Review Council (DSARC) procedures and federal budget process influence system acquisition. Department of Defense (DoD) directives and Air Force regulations govern both system acquisition and software development. Data for this project include directives, regulations, and analyses of procurement, system acquisition, and software development.

IV. Conclusions: Weapon system software development has the following characteristics: changing requirements, inadequate cost estimates, and unknown risks. As a result, either a cost-plus-fixed-fee (CPFF) or cost-plus-award-fee (CPAF) contract is an appropriate pricing arrangement.

Chapter One

PROJECT INTRODUCTION

Former Deputy Undersecretary of Defense Frank Carlucci reemphasized the policy to "employ contract types that are appropriate, considering all the facts and circumstances involved in a specific acquisition" (33:1). This reemphasis is especially important for software development contracts, not only because of the large Department of Defense (DoD) software investment, but also because "software acquisition and contract type [are] often mismatched" (13:58). This staff analysis project determines *what contract pricing arrangement, as described in the Federal Acquisition Regulations (FAR), is appropriate for the development of operational software during weapon system acquisition.*

This first chapter introduces the software problem and analysis approach. Chapter Two describes the procurement, acquisition, and budget processes in detail and their effects on pricing arrangement, while Chapter Three is an analysis of software development for the "facts and circumstances . . . in a specific acquisition". The software pricing arrangement selection is in Chapter Four. Chapter Five presents final findings and conclusions with recommendations for further study in Chapter Six.

This chapter describes the staff analysis project by first discussing the growing importance of software in systems acquisition and some software problems. It then highlights processes that affect contracting for software: the procurement process, the acquisition process, and the budget process. Finally, this chapter describes the analysis approach for the project.

BACKGROUND

An increasing interest and debate within Congress are weapon system acquisitions such as the F-15 and F-16 aircraft, and the small intercontinental Ballistic Missile (ICBM) and Peacekeeper missile systems. Historical cost overruns, difficulties with production schedules, and inadequate follow-on support are major concerns that affect program cost (23:62). They are also three acquisition goals that the Department of Defense (DoD) and Congress review (23:60). Regardless of the weapon system, any acquisition includes software development. Software is now a critical performance and cost element of weapon system acquisition.

Software Importance

The reason for the critical performance and cost impact of software is

rapid advances in computer technology. Rapid advances in technology mean wide-spread use of computers and microprocessors. Embedded computers (computers that are an integral part of a larger system) in the Department of Defense will increase from less than 10,000 in 1980 to over 250,000 by the end of the decade (13:48). The numbers alone illustrate the expanded use of computers (and software) in defense applications. Increasing software applications mean a greater software cost impact.

Software costs in a computer system development now exceed hardware costs (21:1; 5:74). The growth in software costs relative to hardware costs, shown in Figure 1, is due to decreasing hardware costs and an increasing reliance on software to perform system functions. Because of that reliance, some estimates are that software development is 55-70% of the acquisition costs for major Air Force weapon systems (30:19).

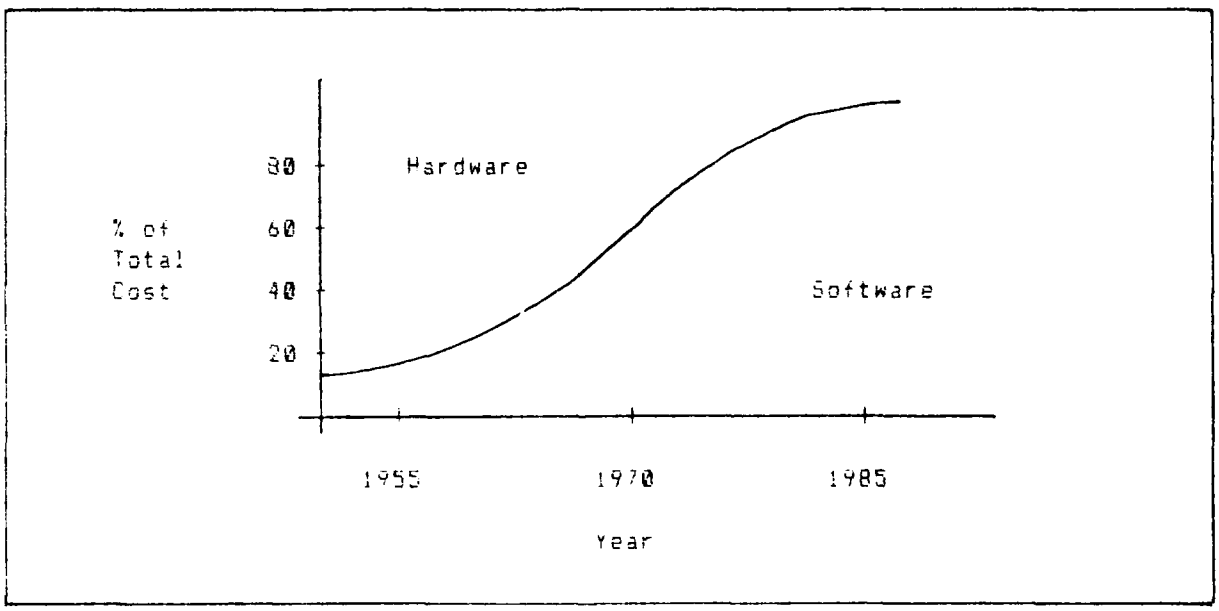

Figure 1. Hardware/Software Cost Relationship

Besides Air Force acquisition costs, software is now a major part of the DoD budget. The DoD software investment of $3 billion in 1974 will grow to $24 billion in 1984 (9:10; 13:48). This rising cost of software development includes significant costs to maintain software. "The cost of maintaining software is estimated to account for about 75 percent of software [life-cycle] costs" (6:20). In terms of either cost or performance, software is an important part of a weapon system. Cost and performance are also software problems.

Software Problems

Significant problems continue to plague software. While new technologies ease the situation, "software overruns still occur, schedules still slip, and software products still fall short of their goals" (5:73). Studies addressing those problems list such factors as incomplete requirements, poor design, lack of standards, and insufficient testing (5:73-74). But other studies cite "insufficient management discipline" (9:17). Still others add "inadequate acquisition planning" and a mismatch between "software acquisition and contract type" to the list (13:68). With the reemphasis on using appropriate pricing arrangements and the recent FAR release, it is necessary to correct that "mismatch".

SYSTEM DEVELOPMENT PROCESSES

Determining an appropriate contract strategy, specifically the pricing arrangement to stimulate contractor performance, requires considering the procurement, acquisition, and budget processes. The procurement and acquisition processes make up key interrelated parts of the system development process. The budgeting process adds additional constraints and considerations. Each impacts the suitability of a particular contract type.

Procurement Process

Highly specialized and complex contract law regulates Government procurements and pricing arrangements. Agencies of the Government must procure supplies and services in accordance with numerous laws, regulations, directives, and policies. The recently released Federal Acquisition Regulation, whose index alone requires 34 pages, contains many of those requirements.

Government agencies must apply the new FAR as well as procurement policy guidance to each procurement and every contract. Former Deputy Undersecretary of Defense Frank Carlucci reemphasized the policy to "employ contract types that are appropriate, considering all the facts and circumstances involved in a specific acquisition" (33:--). Government agencies must now apply that policy within FAR constraints. Among the FAR constraints are those that describe both the application and limitations of contract types (pricing arrangement) throughout the acquisition cycle.

Acquisition Process

The framework for control of the acquisition process is the Defense Systems Acquisition Review Council (DSARC). In May 1969, the DSARC established a weapon system acquisition concept of decentralized management with centralized control of key development decisions (22:1). Although there have been procedural changes in this approach, the DSARC review process for system acquisition is not substantially different than it was in 1969. The four acquisition phases (concept exploration, demonstration/validation, full-scale development, and production/deployment) have key decision points or milestones (24:44-47). The budgeting cycle also affects the acquisition process.

Budget Process

The budget process involves both DoD and Congress. The planning, programming, and budgeting system (PPBS) is a key DoD step in weapon system acquisition. "Approval of the [Program Objective Memorandum] POM constitutes the beginning of the acquisition process" (24:43). The PPBS is a process that identifies needs, determines resource requirements, and allocates resources (31:8). Each PPBS cycle "results in the annual DoD budget request which goes to the President for inclusion in the budget . . . to Congress" (31:8).

The federal budget undergoes a rigorous Congressional review during the budget enactment process. Three key committees in Congress review defense programs and budgets. This review often changes both programs and budgets (26:178-180). As a result, this process is also a factor for analysis.

ANALYSIS APPROACH

To determine the appropriate contract pricing arrangement for software developments, this staff analysis project determines characteristics of the procurement, acquisition, budget, and software development processes that affect the selection of a pricing arrangement. The pricing arrangement selection criteria are the FAR contract applications and limitations. This analysis approach, shown in Figure 2, relies heavily on direct data sources.

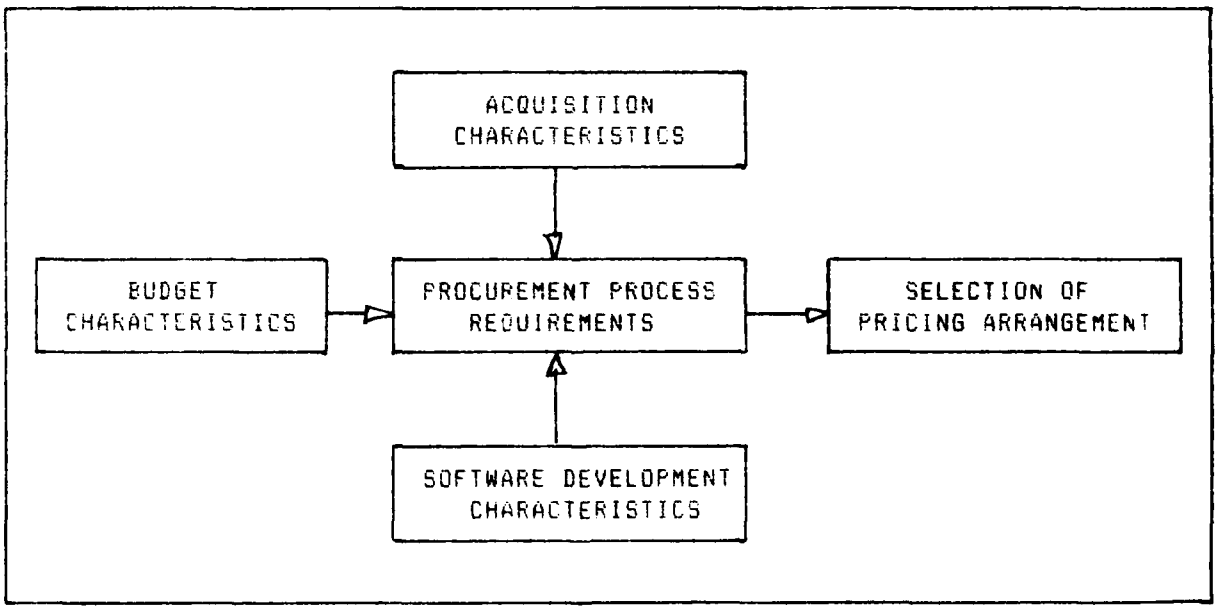

Figure 2. Project Analysis Approach

Data Sources

Sources for the procurement process analysis are the FAR, Defense Acquisition Regulation (DAR), Armed Services Procurement Manual, course material for Government Contract Law, and professional journals that have studies and analyses of the federal procurement system and its application.

Sources for the acquisition process analysis are DoD directives, military standards, Air Force regulations, guidebooks on acquisitions, and professional journals that report results from acquisition process studies and analyses.

Sources for budget (PPBS and enactment) characteristics are Air Command and Staff College phase material and professional acquisition journals that report results of analyses of the budgeting process.

Sources for analysis of the software development process are DoD directives, military standards, Air Force regulations, guidebooks on acquisitions, and professional journals that report results from studies and analyses of the software development process.

Limitations

It is possible to classify weapon system software into three categories: operational, support, and auxiliary software. Operational software are computer programs with a direct link to the weapon system. Support software are computer programs needed to maintain weapon systems but not directly linked to the system. Auxiliary software are computer programs used to develop, test, or maintain operational or support software. This study only considers operational software development because that software is critical in satisfying operational weapon system requirements.

SUMMARY

The increasing debate within Congress on budget cuts to reduce the deficit demand that the Government procure its needed systems properly (23:62). Software is now a critical weapon system cost and performance element. The Department of Defense must properly procure this major element and correct the mismatch between software acquisition and contract type. The first step in determining the appropriate contract type is to consider the Government weapon system procurement process.

Chapter Two

THE GOVERNMENT WEAPON SYSTEM PROCUREMENT PROCESS

The government awards contracts to "acquire necessary supplies and services of the desired quality, in a timely manner, and at a fair and reasonable price" (15:1A1). The procurement process is the same regardless of the "supplies and services". However, the acquisition process described in the Office of Management and Budget (OMB) Circular A-109 structures weapon system developments. The budget process affects both procurement and acquisition. This chapter describes these processes and their impacts on contract selection by first discussing the federal regulatory system for procurement. It then describes acquisition, fiscal (budget), and research and development (R&D) cycles in the government weapon system procurement process. Finally, it summarizes considerations for contract pricing arrangements.

The Regulatory System

Accomplishing the immediate objective of quality, timeliness, and a "fair and reasonable price" requires satisfying restrictions from agency policies and laws enacted by Congress. Because of these restrictions, Government representatives are not free to obtain supplies and services in an arbitrary manner. Agencies of the Government have only a limited, specifically delegated authority to contract (14:1). On the other hand, private parties or companies may generally contract as they please. While the private party is concerned with rules or laws that would prevent a specific contract action, the Government representative must determine a legal authority which permits a specific contract action (14:1-2).

As a result, Government contract law is highly specialized and complex. Legal authority includes statutes, executive orders, judicial decisions, and regulations. The Federal Acquisition Regulation (FAR) is especially important. FAR provisions are issued under statutory authority, have the force and effect of law, and provide mandatory contract clauses (18:1). The FAR establishes a single regulation for all Executive agencies procuring supplies and services with appropriated funds (funds budgeted by Congress). As a replacement for the Armed Services Procurement Regulation (ASPR), Defense Acquisition Regulation (DAR), and NASA procurement regulations, the FAR is intended to:

a. produce a clear, understandable document that improves uniformity in the acquisition process;
b. reduce the growth of agency acquisition regulations;
c. implement recent recommendations from Federal and Congressional commissions; and

d. improve agency, industry, and public participation in developing and maintaining regulatory constraints (18:1).

Government Versus Private Contracting

The FAR places strict limits on Government contracts. These limits are partially due to inherent differences between Government and private contracting. Differences for Government contracting include: public policy objectives for ensuring legal equality of all private parties (treat everyone the same), social objectives (minority-hiring goals), and public oversight of funds (extensive cost accounting). Table 1 shows a more detailed comparison of federal versus private procurements.

Area	Federal	Private
1. Status of parties	government writes rules or is pre-eminent party	legal status of supplier and buyer equal
		advantage company size or financial status
2. Accountability	oversight of funds	general accounting standards and ethics
	legal procedures	
	political review	
	public access	
3. Contracting process	detailed procedures	relatively simple
	detailed documentation standards	individual company policies, standards, and documentation
	legal restrictions	
4. Objectives	public use/benefit	production needs
	agency use only	commercial needs
	multiple objectives	profit and loss
	social goals	competitive posture

Table 1. Federal and Private Procurement Comparisons

[illegible] that comparison emphasizes differences between public and [illegible] private contracts, legal principles of offer, acceptance, consideration, competent parties, and definite terms apply to both (14:7). The basic contract solicitation and award processes for the two procurements are also similar (14:7).

Federal Procurement Process

The activities, Figure 3, from the 1972 Commission on Government Procurement report a model of the federal procurement process are similar to those in the private sector (1:III). The federal procurement process activities of planning, solicitation, selection, award, and contract administration work within statutory and regulatory limits to satisfy the funded need. These activities are summarized below:

a. *Planning* - The agency develops an overall contracting strategy. There is a review and validation of specific needs and objectives. The agency then starts individual procurement actions to meet those needs.

b. *Solicitation* - The procuring agency completes the contract Statement of Work (SOW). The SOW includes tasks, schedules, delivery items, and other performance and quality requirements. This SOW is an essential part of an invitation for contractors to

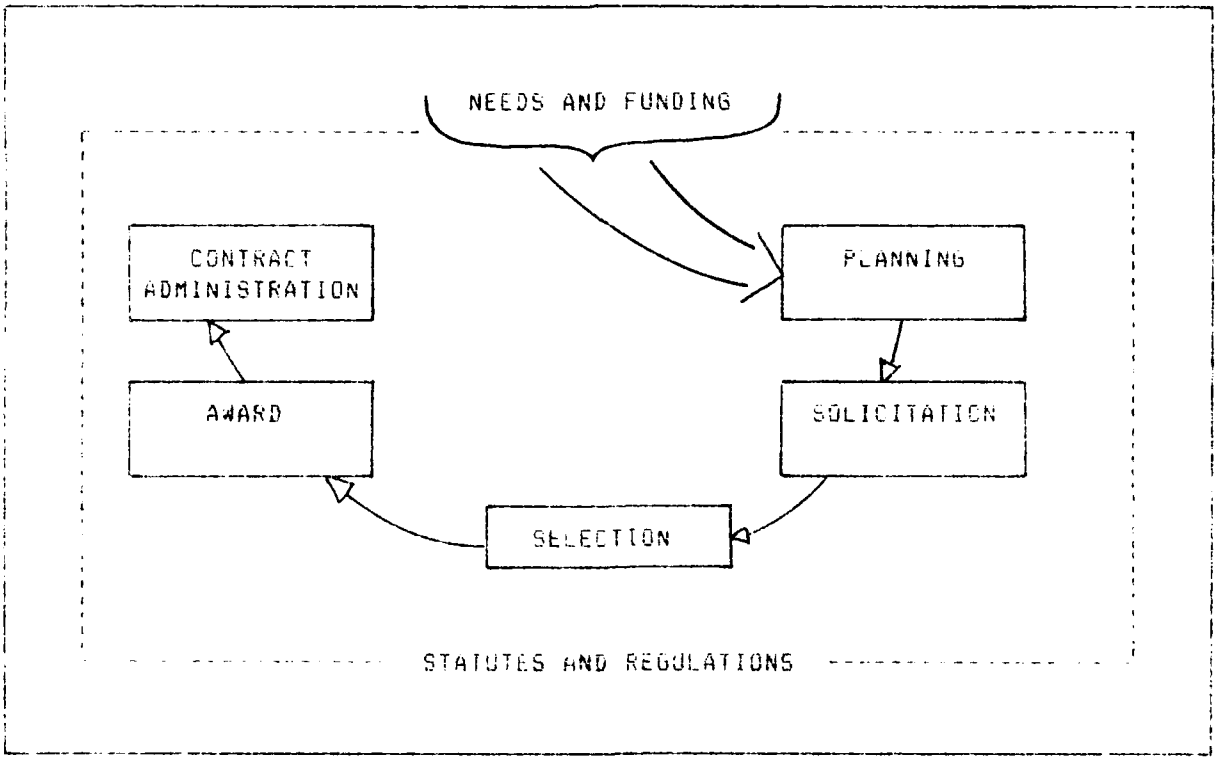

Figure 3. Federal Procurement Process

bid (make an offer) on needed services or supplies. In some cases, the contracting office releases a draft SOW for comment.

c. *Selection* - The procuring agency evaluates all offers. The evaluation criteria may be price, technical capabilities, or a combination of price and other factors.

d. *Award* - The Government accepts an offer and signs a contract.

e. *Contract administration* - The contractor performs the specific contract tasks. Both the contractor and the contracting agency perform contract management.

A key part of this procurement process is to determine contract strategy. This includes determining pricing arrangement.

Pricing Arrangements

Part of contract strategy is selecting a pricing arrangement such as a fixed-price or a cost-reimbursement contract. In the *fixed-price* arrangement the contractor agrees to deliver a product or perform a service while the Government agrees to pay a price equal to the firm price specified in the contract. The contractor's actual costs have no effect on the agreement to deliver nor on the Government's agreement to pay. The contractor's ability to avoid a loss or make a profit is directly related to controlling costs. If actual costs are less than the negotiated price, the difference is profit. If actual costs are more, the difference is loss. The contractor assumes the performance risks in a fixed-price contract (15:2C1-2C24).

In *cost-reimbursement* efforts, the Government agrees to reimburse the contractor for all reasonable and allowable costs that are allocable to contract performance (15:2C1-2C24). The contractor agrees only to use a best effort to complete the contract within cost estimates. The contractor is not obligated to continue performance when the estimate is exceeded nor is the Government obligated to reimburse costs in excess of the original estimate (15:2C1-2C24). In this contract type, the Government assumes performance risk since the Government must pay whatever costs are required to complete the effort or be satisfied with whatever effort was made.

The FAR discusses selecting appropriate pricing arrangements. Pricing arrangements stimulate the performance of the contractor doing the work by defining several ways for the contractor to receive payment and profit. The choice of a fixed-price or cost-reimbursement contract often rests on performance risk. The FAR and the Armed Services Procurement Manual address contract type, risk, and profit relationships:

1. Both the Government and the contractor should be concerned with harnessing the profit motive in stimulating performance.
2. Success in effectively harnessing this motive requires negotiating sound performance goals and standards.
3. Contract type should tie profits to contractor efficiency in controlling costs and meeting performance, reliability, quality, and delivery requirements.
4. There are situations where the profit motive may be secondary.
5. The firm fixed-price contract is the most preferred method for

harnessing the profit motive because the [illegible] cost responsibility.

. The specific type of contract should be [illegible] of risk [illegible] 2.24).

[illegible] arrangement to satisfy [illegible] estimates, type and [illegible] adequacy [illegible] accounting system [illegible] is minimal [illegible] be [illegible] with an acceptable [illegible] a firm fixed-price contract is preferred. However, as the [illegible] more significant, either [illegible] price or cost-type [illegible] employed (17:1.5.101). A common way of presenting this [illegible] Figure 4.

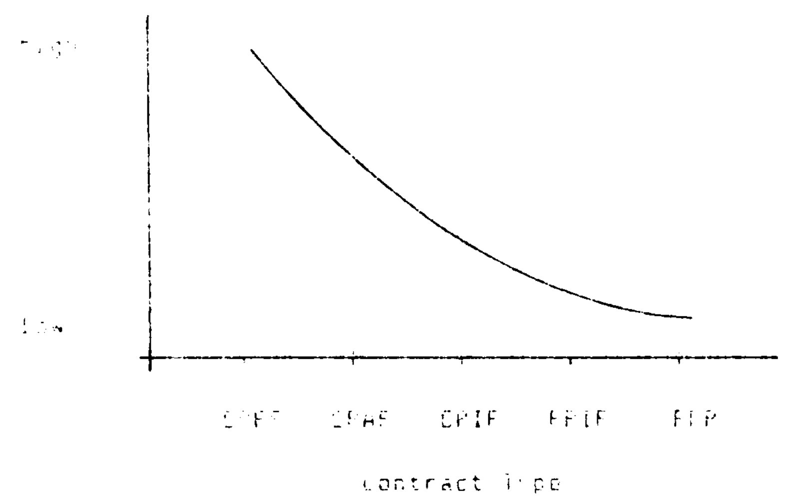

Figure 4. Contract Type Versus Risk

[illegible] two basic types of contracts have many variations in the [illegible] calculate profit. The intent in the different contract [illegible] to harness the profit motive, reward performance, or [illegible] for [illegible] risk or innovation by selecting the most appropriate contract type.

[illegible]

There are five major contract types, each with specific [illegible] limitations.

Firm-Fixed-Price (FFP) Contract. The firm-fixed-price contract provides for a payment which is not subject to any adjustment for actual costs. The difference between negotiated and actual costs is profit or loss. This type of contract places maximum risk upon the contractor. The FFP contract is suitable when reasonably definite design or performance specifications are available and the Government can establish price (15:203; 17:16.2).

Fixed-Price-Incentive-Fee (FPIF) Contract. The FPIF contract is a fixed-price type contract with a provision for adjusting profit. How well the contractor meets performance or delivery requirements increases or decreases profit. FPIF contracts are appropriate where incentives can improve performance levels or delivery. Fixed-price-incentive-fee contracts should not be used unless the contractor has an adequate accounting system. An FPIF should not be used unless it is likely to be less costly than other methods of contracting for the same item (15:204-209; 17:16.403).

Cost-Plus-Incentive-Fee (CPIF) Contract. The cost-plus-incentive-fee contract is a cost-reimbursement contract with adjustments in fee (profit). The relationship of actual costs to target cost increases or decreases profit. The CPIF contract is suitable primarily for development and test. It should be used when it is likely that a profit adjustment is a positive incentive for effective management. The CPIF contract is appropriate when development is highly feasible, there are well-defined performance objectives, and the contract is administratively practical to manage (15:2015-2018; 17:16.404-1).

Cost-Plus-Fixed-Fee (CPFF) Contract. The CPFF contract is a cost-reimbursement contract where fee (profit) does not vary with actual costs or performance. Because fee does not vary, there may be only a minimum incentive for effective management of costs. The CPFF contract is suitable for research projects or when the needed level-of-effort is unknown. This type of contract normally should not be used for development of major weapons where there is a high probability that development, performance objectives, and schedule are achievable (15:2021-2024; 17:16.3).

Cost-Plus-Award-Fee (CPAF) Contract. The CPAF contract is a cost-reimbursement contract with special fee (profit) provisions. It provides a profit incentive in cases where it is difficult to quantitatively measure performance. Award criteria vary, but may include quality, management, and schedule factors. The CPAF contract is suitable for level-of-effort contracts where the performance of services is clear but determining level of achievement is subjective. It is also suitable for efforts where it is difficult to establish definite milestones. There are limitations to its use: it should not be used to avoid a CPFF contract, or when procurement is for Engineering Development or Operational System Development activities (15:2018-2021; 17:16.404-2). These activities are part of the FAR's R&D cycle for a system life cycle.

System Life Cycle Models

The total system life cycle, Figure 5, includes system acquisition, research and development (R&D), and fiscal year budget cycles. A weapon system life cycle, as defined in AFR 800-2, "Program Management, and AFR 800-3,

... Defense Systems ... consists of four phases ... and operation (25:5)

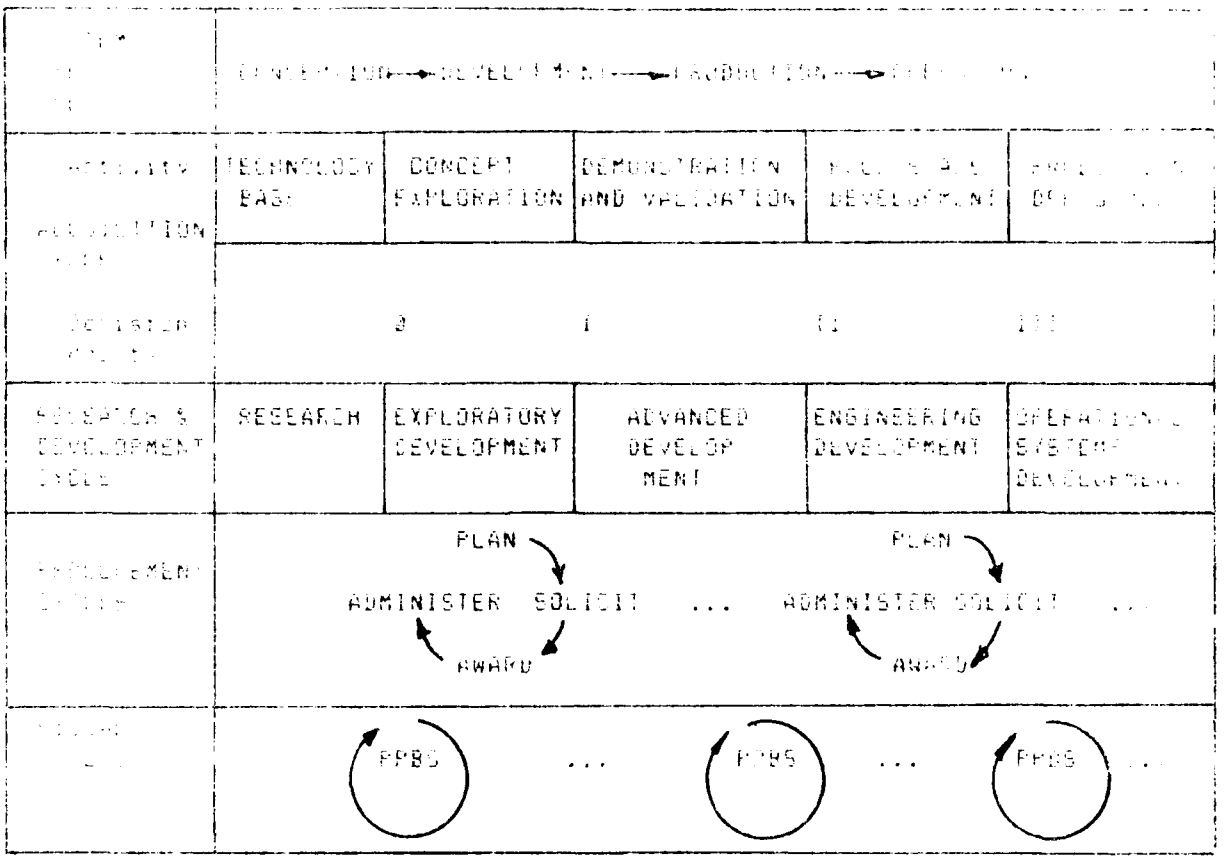

Figure 5. Interrelated System Cycles

... Acquisition Cycle

... Defense Acquisition Review Council (DSARC) review ... in DoD governs weapon system acquisition. The original ... review or milestone points; the fourth was introduced in ... The DSARC was charged with evaluating major system programs ... (milestones) and advising . . . the Secretary of Defense ... status and readiness of each program to advance to the next ...

... directives describe the process. Two key documents are ... 5000.1, "Major System Acquisitions", and DoD Instruction 5000.2, "Major system acquisition procedures". The first document presents ...

cept, guidance, and policies for major weapon systems acquisition; the second provides specific tasks and responsibilities (24:41-42). While there is now some flexibility in scheduling milestones, each milestone has a specific purpose:

a. At *Milestone 0*, the Secretary of Defense approves the start of a new program following analyses that identify a mission need.
b. At *Milestone I*, the Secretary of Defense, after a DSARC review and recommendation, selects a specific concept from a number of alternatives based on such factors as costs, schedules, mission objectives, supportability, industrial base, and affordability. This milestone occurs at the end of the concept exploration phase. Concept exploration emphasizes identifying alternatives and maintaining competition.
c. At *Milestone II*, again following a DSARC review and recommendation, the Secretary of Defense gives approval to begin or proceed with full-scale development based on performance definition, costs, schedules, risks, and supportability. This milestone normally occurs at the end of the demonstration and validation phase where there is extensive prototype testing. It may occur later in the system development phase to refine cost, schedule, and performance requirements or estimates.
d. At *Milestone III*, either the Service Secretary or the Secretary of Defense decides to produce and deploy the system (24:43-47).

Although the DSARC review process instills discipline into acquisition, it also has faults (22:4,53; 3:13). A recent study of 16 programs developed under the DSARC process concludes that although effective, the review process is inefficient (22:iv). Among the inefficiencies are:

a. decisions are not considered to be binding budget decisions--since the budget process operates independently of the DSARC review process, changes to programs often do not find their way into the budget, are appealed during the budget process, or are reversed during the budget cycle;
b. there is a perception of micromanagement--rather than considering broad system issues, DSARC reviews overemphasize technical issues and engineering solutions at subsystem or component levels;
c. strategies and program direction change whenever the staff changes (every 2-3 years)--alternatives are reconsidered, studies reaccomplished, and previous phases repeated as the new staff reviews earlier efforts; and
d. Congressional authorization or appropriation bills often include program tasks, limitations, and guidance (22:51-55).

Fiscal Cycle

The Planning, Programming, and Budgeting System (PPBS) ends in the DoD budget input for the Congressional budget process. Although the PPBS completes a cycle each year, "several cycles are in progress simultaneously" (31:8). Because of that, the PPBS cycle is not time-phased exactly as shown in Figure 5, but is a series of overlapping cycles. These two interrelated PPBS and

...political model ...ities impact system development.

...the PPBS system and Congressional budget enactment ... program instability. PPBS contributes to cost increases in a weapon ... One reason is a tendency to ensure program funding for the upcoming ... year at the expense of long-term weapon system implications (20:1). ... costs are sometimes purposely understated either because personnel ... program to fit available funding rather than the funding required ... for or because contractors purposely lowered their cost estimates ... contract" (27:96). As a result, program costs for later fiscal years increase in hopes of recovering. This produces instability in program requirements and schedules. This reenforces Congress' view that "early cost, schedule, and performance estimates are consistently overly optimistic and highly unrealistic" (27:97).

...Congress' inability to enact budget legislation by the start of the fiscal year affects program stability. Congress uses a continuing resolution authority to fund programs when it fails to enact budget legislation. A continuing resolution allows the expenditure of funds at the current rate. This delays procurement actions and puts programs on hold. Among the impacts are: difficulty in long-range planning; reduced management flexibility; funding uncertainty; and unstable program schedules (28:198). To some degree, these impacts occur every year.

...fiscal years 1980-1984 began with a continuing resolution ranging from ... weeks to 11 weeks with an average of 10 1/2 weeks before Congress enacted a ...eferal budget (34:--). This problem is a recurring one. "Since 1972, thirty-four continuing resolutions have been enacted into law . . . Since 1976 . . . only one were all appropriations bills enacted by the beginning of the fiscal year, even in that year a continuing resolution was needed to fund some ...tions" (28:198).

...ed Development (R&D) Cycle

...research and development cycle in the system model, Figure 5, con... four important activities for pricing arrangement considerations. The ... discuss these activities as an aid in determining pricing arrangement.

...definitions are:

... *Research* - includes all scientific study and experimentation efforts directed toward increasing knowledge and understanding in those fields of the physical, engineering, environmental and ...te sciences related to long-term national security needs. It ... the fundamental knowledge required for the solution of mil... problems.

... *Exploratory Development* - includes all efforts directed toward the solution of specific military problems, short of major development projects. It involves only minor development effort. The dominant characteristic of this category is evaluating proposed solutions to specific military problems for feasibility.

... *Advanced Development* - includes all efforts for projects which

are developing prototype hardware for test. The prime result of this type of effort is proof of a design concept rather than hardware development.

d. *Engineering Development* - includes any projects in full-scale engineering development. There is no approval for system production yet.

e. *Operational System Development* - includes those projects still in full-scale engineering development but with approval for production (16:4-101; 17:16.104).

There are both general and specific pricing arrangement guidelines for those R&D activities. General guidelines include:

a. A contract other than FFP should be used when: contracting for research and development; when price competition is not present; when cost or pricing data available does not permit sufficiently realistic estimates of probable cost of performance; or uncertainties cannot be evaluated.

b. It is possible for different parts of a project to fit several different categories. The contract must be selected to fit the work required not the program classification (17: Part 16).

There are also specific guidelines, Table 2, that describe characteristics of the R&D phases and the appropriate contract types for each phase. As shown, there is more than one appropriate contract for any general R&D activity. Specific projects may have other considerations for a final contract selection. Table 2 groups together R&D categories with similar characteristics.

The Research and Exploratory Development categories have similar characteristics. An important one is a lack of definitive requirements. As a result, several cost-reimbursement contracts are appropriate. The selection depends on other factors including risk. Similarly, the Engineering Development category shares such common characteristics as engineering design and prototypes with the Operational System Development category. In this case, the degree of project definition (requirements) and risk are among factors to consider.

There are few restrictions in the Advanced Development category. Because this phase often has many major changes as a result of systems analysis and cost studies, the contract is usually a CPFF. In cases where it is possible to define measurable cost, schedule, or performance criteria, incentives are possible.

Summary

The weapon system procurement process includes procurement, acquisition and budget processes. The procurement process defines how to contract and when to use certain pricing arrangements. In general, when risk is minimal, a fixed contract is appropriate. As uncertainties increase, however, cost-reimbursement contracts are appropriate. As an aid in that selection, the FAR defines R&D categories that are similar to acquisition process activities. The acqui-

	[illegible]	[illegible]
	[illegible]	[illegible]
	risk unknown	
	government technical direction and control extensive	
	[illegible] primary objective	
[illegible] develop	experiment to show concept feasibility	no restriction on contract type, but often a CPFF
	advanced technology	
	systems analysis	incentives used if there are measurable targets
	cost studies	
	hardware designs	
	many major changes	
[illegible] development and operational system [illegible]	objective is production or development	select system on degree of [illegible] definition
	engineering design and demonstration	accuracy of cost estimates
	producibility	risk
	production [illegible] types	incentives
	tooling	degree of [illegible] test [illegible] direction
	test equipment	

Table 2. Contract Types for R&D Activities

sition process formalizes weapon system development. Congress not only affects these processes during the budget process as it reviews programs, but also by its inability to pass a budget at the start of a fiscal year. The following characteristics result from the interrelationship of all these activities:

a. while the DSARC review process is effective in formally reviewing programs, it is inefficient--continued review, micromanagement, and resulting program instability; and
b. budget and fiscal cycles add to program instability--unrealistic program costs, lack of a budget at the start of the fiscal year, and Congressional program direction in budget bills.

These general factors for weapon system development are considerations when selecting pricing arrangements. The next step is to specifically consider software development for other factors affecting pricing arrangement.

Chapter Three

SOFTWARE DEVELOPMENT

To correct the mismatch between software acquisition and contracts requires a detailed look at software development. This chapter highlights significant costs and problems with software and describes the current software development model. It then describes changes in that model as a reaction to software problems. Finally, it summarizes software development characteristics affecting pricing arrangement.

SOFTWARE COSTS AND PROBLEMS

Software development is a major weapon system cost. There are estimates that 85-70% of the acquisition costs of major Air Force weapon systems are for software development (30:19). Additionally, the DoD software investment will grow to $24 billion in 1984 (9:10; 13:48). While these costs often result from expanding software applications, high software costs are also due to development factors. The following are major examples:

a. the labor-intensive aspect of software development often requiring highly skilled and creative programmers;
b. extensive software testing during development;
c. changes in a program's design and code as errors are found and then corrected; and
d. vague or changing requirements.

Another reason is the cost to maintain software. "The cost of maintaining software is estimated to account for about 75 percent of software costs" (9:20). The above reasons for high software development cost also apply to the high cost of maintaining software. While hardware is maintained by replacing worn or failed parts with new ones, it is not possible to maintain software by replacing it with an identical copy of the original program. Software maintenance means redesign requiring the same tools, techniques, and skills as development (11:343). That redesign is often to correct software so "much of this expense [for software maintenance] is attributable to time spent fixing up software that was not correctly developed in the first place" (6:20).

The need to fix software is one problem with software developments. Others are overruns, late deliveries, and system failure. These often occur at the same time. Cost overruns of "four times the original estimates . . . with half the planned capability are not uncommon" (30:5). Overruns often occur because of an inability to accurately estimate costs.

Models for estimating software costs are "poor and there is little correlation from one model to another" (13:67). Particularly critical for weapon system software acquisition is that models "do not produce good estimates 3 to 5 years in advance, at the time the initial budgeting estimates are made in the Program Objective Memorandum" (30:5). With the difficulty in estimating costs, the resulting cost, schedule, and performance problems are not surprising. Another reason given for those problems is failure to follow an adequately structured and properly managed development process (21:1; 13:63).

SOFTWARE DEVELOPMENT PROCESS

To follow a structured and properly managed software development process requires recognizing both the role and nature of software. The software role changes during weapon system development. In early phases of weapon system development, software supports hardware engineering models and prototype tests. As the system development progresses, software supports test tool and simulation development while continuing to support hardware development. Finally, software is a distinct product in the weapon system. With all these roles, a properly structured and managed development must plan to both develop software and support other activities. Software can readily support other activities because of its nature.

Software programs are easy to modify while software development is iterative. Software modifications can quickly change system functions for hardware tests, new requirements, or design corrections (13:69). (Appendix A gives examples of modifying software to improve system functions.) This creates the incorrect impression that since it is easy to modify software, modifying software is easy.

Modifying software is not easy because it means redesigning the program. This requires analysis, coding, and testing--the same tasks needed to develop software. In fact, "current practices for modifying delivered software systems frequently result in excess costs, failure to realize performance potential, [and] systems out of action for unreasonable lengths of time" (13:69). This means yet another modification. Developing software that works properly, then, is an iterative process.

Software development is iterative because of changes "to make the system meet the original requirements" (13:69). Changes often correct errors which fall into one of three categories: requirements, design, or code (these are also three software development phases) (5:74). Regardless of the system, software, or testing program, errors are detected during each phase of software development " . . . from every major category. And more importantly, each phase caught errors which should have been detected earlier" (2:79). This means that during the design phase there are errors in both design and requirements; and during the test phase, there are errors in requirements, design, and code. But software development process models have not shown software modifications or software's iterative nature.

[illegible] Software Model

A simplified model of the current software development process has a "sequential set of well-defined phases, each with specific products [illegible] reviews" (5:74). Mil Std 1521A, "Technical Reviews and Audits for Systems, Equipment, and Computer Programs", defines the technical reviews and audits which ". . . monitor the orderly evaluation of software in sequential steps [illegible] the development process" (29:1).

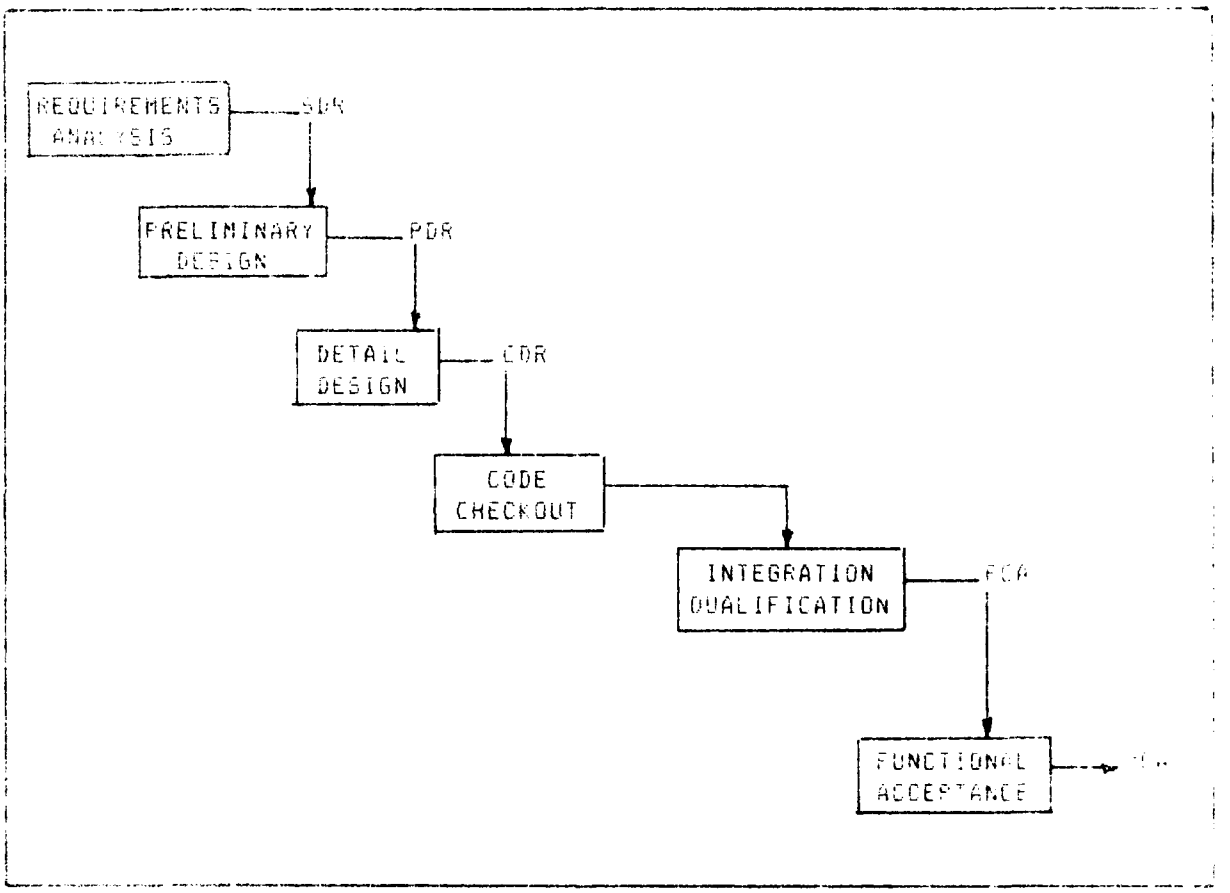

Figure 5. Software Development Model

Each technical review and audit has a specific purpose. Technical [illegible] reviews emphasize engineering and design while audits emphasize [illegible] qualification and configuration verification:

a. System Design Reviews (SDR) are to evaluate the entire [illegible] concept (hardware and software) and the distribution of [illegible]

requirements to each item;

b. Preliminary Design Reviews (PDR) are to evaluate basic software design for completeness, adequacy, and compatibility with software and system requirements;
c. Critical Design Reviews (CDR) are to evaluate detailed design prior to software coding;
d. Functional Configuration Audits (FCA) are to verify software performance against requirements; and
e. Physical Configuration Audits (PCA) are to examine the coded program against its documentation prior to Government acceptance (29:Ch 4).

THE CHANGING SOFTWARE MODEL

In reality, software phases are not distinct or sequential steps. Requirements analysis does not stop at a distinct point, nor does preliminary design wait until all requirements are defined. Instead, all phases blend together throughout software development as in Figure 7. Each phase also repeats as software matures. "Several software development life cycles . . . occur during one system development life cycle" (25:5). These software life cycles are software modifications in response to new requirements, more efficient design, or test results.

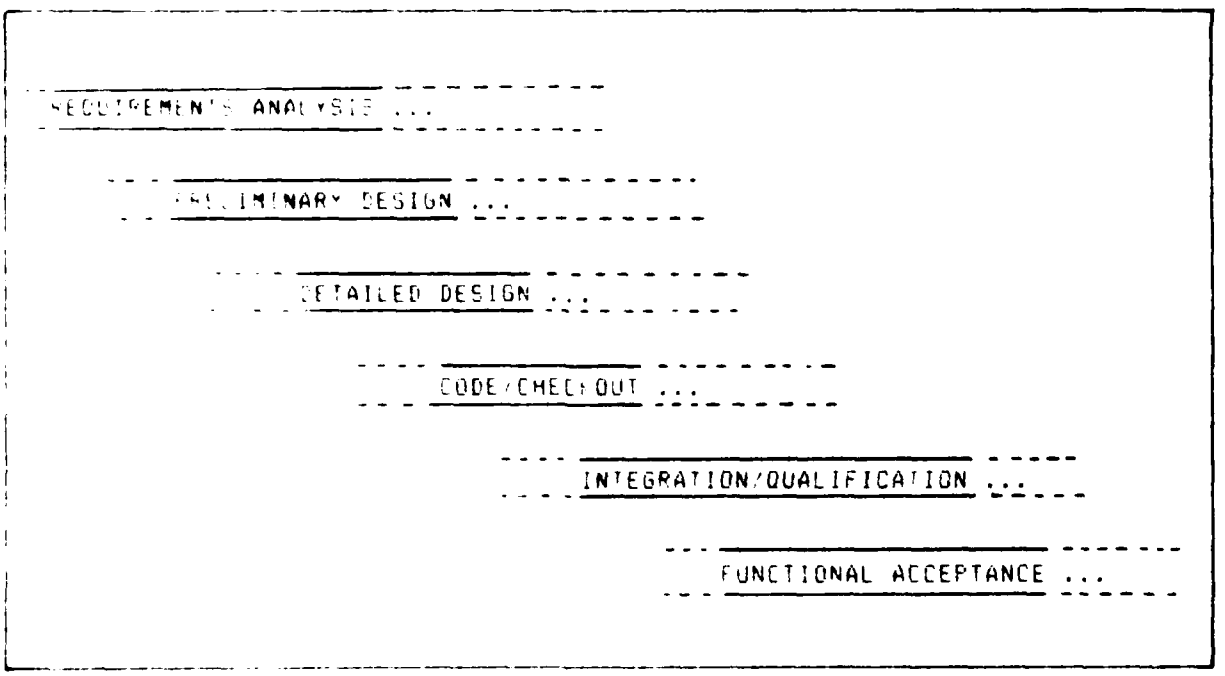

Figure 7. Software Life Cycle Activities

Other software development models exploit software modification [illegible] models recognize that each phase of software development will continue as in Figure 7 to correct errors. Those changes may modify requirements, design, or code since "error categories appeared to be distributed in time (across each phase)" (2:75). To control those changes, other process models [illegible] repeat phases, define software "builds", and add reviews.

In those models, requirements analysis, design, code, and test are [illegible] as in Figure 8. Because software modification is a redesign, it involves all development activities. As an example, Figure 8 shows that from the code and checkout phase it is possible to repeat either requirements analysis and continue or detailed design and continue. Similarly, at any activity, it is possible to repeat any earlier activity. The repetition of development activities and changing requirements are factors that led to software "builds" as a way to control software changes.

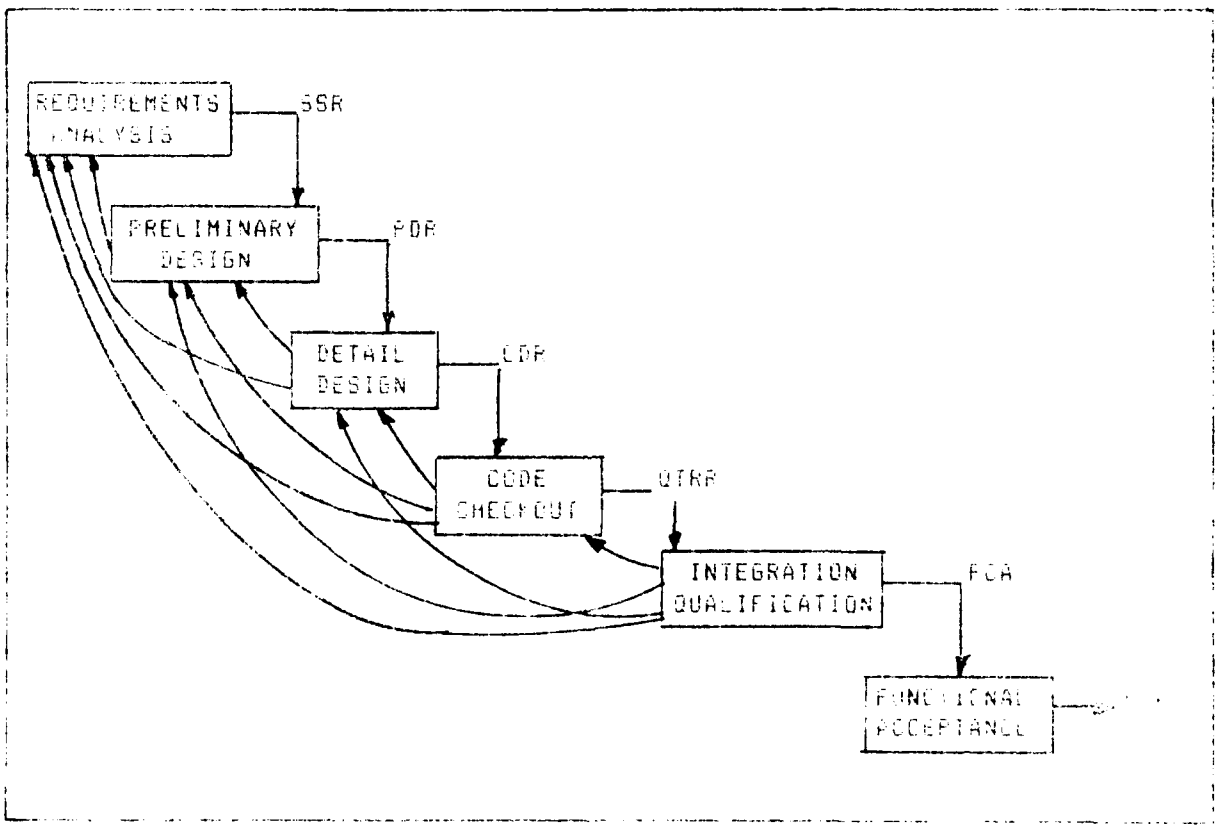

Figure 8. Software Development

Software Development "Builds"

In the "build" approach, software development occurs in stages. Early builds of the software have basic program structure and a subset of requirements. Incremental development, Figure 9, allows progressively refined builds that add to or expand initial capabilities. Changes can be incorporated in the next version or delivery. Figure 9 shows an offset in activities to indicate that build modules are time-phased and activities overlap. Factors that influence the choice of requirements for the first build are hardware development, test-bed requirements, and interface definition. In specifically defining each version, builds help to manage unstructured and uncontrolled changes.

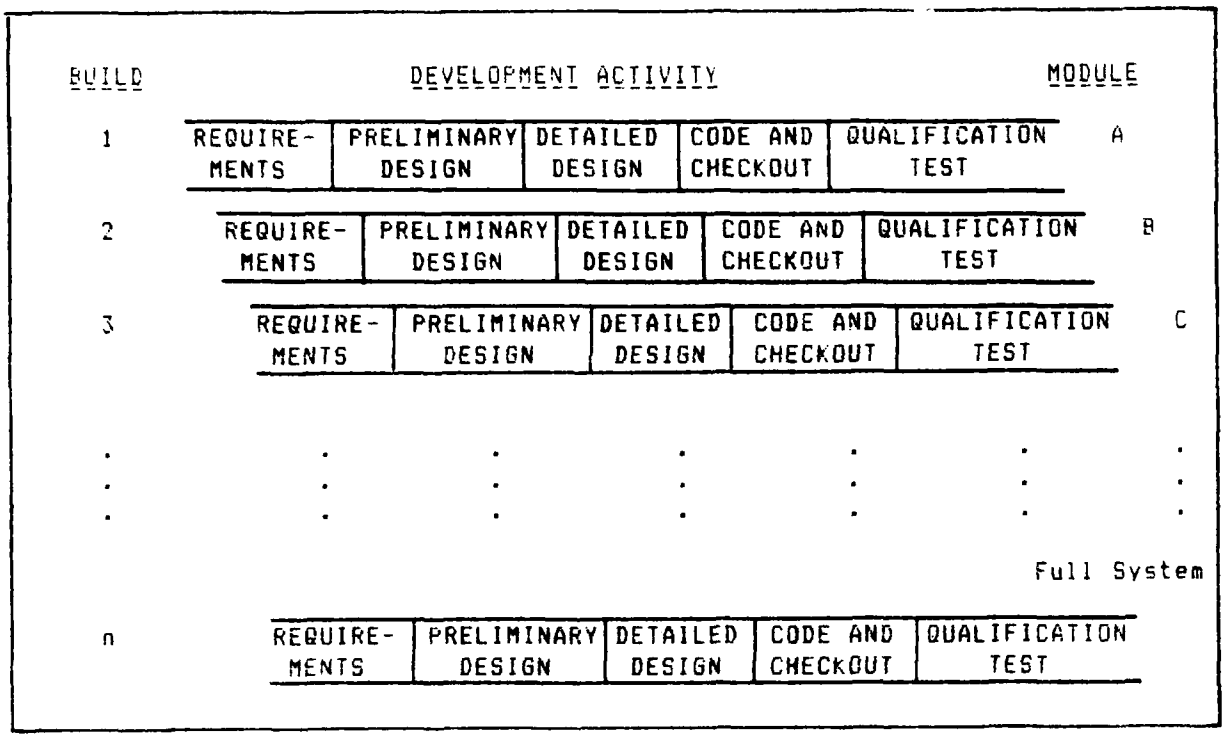

Figure 9. Software Development "Build" Approach

There are several ways to define the capabilities of each build. Guidelines for defining distinct builds include:

a. ensure the build is functionally logical with operations;
b. maximize the uniqueness of added capabilities in each build; and
c. minimize the amount of modification required of previous builds for the new increment (7:271-277).

[illegible]

[illegible] the [illegible] increment [illegible] application program [illegible] interface [illegible] increment [illegible] which [illegible] in later increments, and [illegible] final [illegible] increment. Another approach with the "build" [illegible] of the program.

[illegible] software prototype [illegible] and [illegible] evaluate prototype [illegible] efficiency, and completeness. The next prototype build [illegible] based on test results from the first prototype. This [illegible] this approach, there is a longer time between builds [illegible] analysis.

With [illegible] new approach, software builds solve these develop[illegible]

[illegible] There is a need for early versions of a software [illegible] to exercise hardware interfaces for breadboard or engineering models.
2. First versions of software often do not function properly [illegible]
3. Software development is often a trial-and-error [illegible] problem-solving.

[illegible] Reviews

In all software development process models, reviews and audits [illegible] programs. Some organizations tailor Mil-Std 1521A to include [illegible] views with the build concept:

[illegible] Specification Review (SSR). SSRs are to review [illegible] ments prior to preliminary design. This includes the initial allocation of requirements to specific builds (12:119-127).

Qualification Test Readiness Review (QTRR). One of the [illegible] critical to Government acceptance is the final software [illegible] requirements. These are qualification tests. The objective [illegible] verify the status of the software program, support tools, [illegible] prior to qualification testing (12:119-127).

With software development models reflecting a build [illegible] the reviews cited earlier may repeat during [illegible] SDR for build number 3 would be an incremental [illegible] number of incremental reviews varies for individual programs [illegible] needs a complete set of incremental reviews.

SUMMARY

High software development costs are due to inherent [illegible] problems in development. Development characteristics include [illegible] skilled programmers and extensive testing. Software problems [illegible] changing requirements, poor cost estimates, errors, and [illegible] times. New software development models now depict a blending [illegible]

an iterative development process. These models are often software "builds" that control changes in requirements, design, and code. Key characteristics, then, when selecting a pricing arrangement for software development are:

a. changing requirements;
b. poor cost estimation; and
c. an iterative development process.

These factors indicate that software development is a high risk effort regardless of the system acquisition phase. The final step to correct the mismatch between software acquisition and contracts is to relate these software characteristics and the Government procurement process factors from Chapter Two to the FAR pricing arrangement guidelines.

Chapter Four

SOFTWARE CONTRACTS

[illegible] weapon system procurement and software [illegible] pricing arrangement. This chapter determines [illegible] development for weapon system software by first relating software [illegible] in the system life cycle model shown earlier in Figure 5. It then defines software's relationship to the FAR R&D categories. Finally, it analyzes the FAR pricing arrangement criteria to select the appropriate software development pricing arrangement.

SOFTWARE AND THE LIFE CYCLE MODEL

Software development models and system acquisition directives define software development as a Full-Scale Development (FSD) activity. Software development models begin with establishing software requirements. In Mil-Std 1521A, Figure 8, requirements analysis ends with the System Design Review (SDR). Other models include a Software Specification Review (SSR) as shown in Figure 9. Either of these reviews occurs as the final review prior to submittal of Validation phase products or as the initial review in the Full-Scale Development (FSD) Phase for systems/subsystems not requiring a formal Validation Phase (1Y:3a). Software development design, code, and test fall in the FSD phase. From Figure 5, software development is an FSD activity occurring in the R&D cycle's Engineering Development phase.

SOFTWARE AND R&D CATEGORIES

[illegible] development phase characteristics, Table 2, [illegible] Unlike units, designs, and prototypes apply to software. Engineering type, [illegible] program development. In fact, "software problems [illegible] Major difference is that software development requires no production [illegible] but proceeds directly from full-scale development to deployment (FSD). [illegible] R&D there are several software development life cycles [illegible] This means software has engineering [illegible]

[illegible] design is part of software development. [illegible] start with requirements to develop designs. Designs are progressively refined [illegible] and more detail. At various times, parts of the design are [illegible] for [illegible] by, efficiency, or adequacy. These designs are [illegible] designs that develop into a final design and program. In some software [illegible]

opment models, these designs are prototypes.

Prototypes are complete designs to test program requirements and operational capabilities. A next build or prototype version improves design and code for better efficiency or use. These interim versions are not the final product but a means to arrive at the final design and program. This is consistent with activities in the FAR's Engineering Development phase.

FAR CRITERIA ANALYSIS

Factors in selecting a contract type for Engineering Development efforts, Table 2, include degree of project definition, accuracy of cost estimates, and degree of Government control and direction. These factors determine the appropriate contract type (pricing arrangement).

Project Definition

Weapon system program stability and software development characteristics are key ingredients for project definition. The conclusions in Chapter Two indicate that weapon systems suffer from program instability (a specific example of program instability is in Appendix B). Even if that was not the case, software development problems include "original requirements that are incomplete" (5:73). The iterative nature of software development includes changes in requirements. This is additional evidence that software project definition is poor. (Appendix C shows an example of reported errors in requirements throughout development). Software's poor project definition affects cost estimate accuracy (32:2).

Accuracy of Cost Estimates

There are a number of reasons why it is difficult to estimate software costs. With program instability and ill-defined or vague requirements, "the resulting cost estimate . . . will be imprecise and undependable" (32:2). Even with firm requirements, "current software cost estimation (SCE) models do not produce good results" (30:5). SCE models require estimates of the software program size (30:5). But size estimates are inaccurate (30:5). Even SCE models with factors for program size, complexity, hardware, personnel, and schedule give different estimates for the same project (36:--). The size of the program changes during development as modifications occur.

Modifications during development to fix "software that was not correctly developed in the first place" also affect cost estimates (6:20). These modifications occur from review, analysis, and test. The ability to predict the number of errors or changes during development is limited. "All error prediction models suffer from the inability to predict to the accuracy [desired]" (4:104). Because of that, software development has cost risks.

Risk

The FAR discusses risk in terms of cost and performance. Cost risks are primarily adequacy of Government and contractor cost estimates realistic

Cost-Plus-Fixed-Fee (CPFF) Contract

CPFF contracts are suitable for research or when level-of-effort is unknown. As discussed above and earlier in Chapter Three, software cost estimation models are inaccurate. Changing requirements and modifications throughout development make software level-of-effort unknown. This contract type may be appropriate for software developments.

Cost-Plus-Award-Fee (CPAF) Contract

CPAF contracts are suitable where determining the level of achievement is subjective or where it is difficult to establish definite milestones. When different software designs satisfy requirements, their evaluation is subjective. Meeting the requirements is difficult. Especially difficult is establishing and meeting definite milestones. CPAF contracts, then, may also be appropriate for a weapon system software development.

SUMMARY

Weapon system software development has a lack of firm requirements, inadequate cost estimates, and extensive Government control and direction. These are also pricing arrangement characteristics for a cost-reimbursement contract. The characteristics indicate that software development is high risk during any system acquisition phase. High risk developments normally require a cost-reimbursement contract as shown earlier in Figure 4. Reviewing the three major cost contracts to answer the question what contract pricing arrangement, as described in the Federal Acquisition Regulation (FAR) is appropriate for the development of operational software during weapon system acquisition gives this answer: *a cost-reimbursement contract--either cost-plus-fixed-fee (CPFF) or cost-plus-award-fee (CPAF).* The important part of this conclusion is that software development requires a cost-reimbursement contract. A selection between a CPFF or CPAF requires additional specific acquisition considerations. The individual software program, type of functions, previous experience, computer system, and other areas would help choose between a CPFF or CPFF contract.

The PPBS and budget enactment processes also add to program instability. Findings in this area are:

1. The PPBS contributes to cost increases as unrealistic initial budget estimates cause increases in later cost estimates.
2. Congress' failure to enact budget legislation at the start of a fiscal year cause difficulty in long-range planning, reduced management flexibility, funding uncertainty, and unstable program schedules.
3. Congressional program direction in budget bills adds tasks, constraints, and restrictions on programs.

Software developments also add factors affecting pricing arrangements. These are the findings from the software development analysis:

1. Requirements for software are ill-defined and often change.
2. It is difficult to estimate software program size or software development costs.
3. Software development is iterative as errors are found and corrected.

SUMMARY

The analysis process for this project considered the procurement, acquisition, budget, and software development processes to determine the appropriate pricing arrangement for weapon system software. The findings from each area indicate that software is a high risk effort with characteristics of Research and Exploratory Development activities. This leads to the conclusion that either cost-plus-fixed-fee or cost-plus-award-fee pricing arrangements are appropriate for weapon system software development is

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APPENDICES

Appendix A

MINUTEMAN SOFTWARE MODIFICATIONS

Software programs are easy to modify. The advantage to software modification is that system functions can be changed by modifying software rather than hardware or by minimizing hardware modifications. Both Minuteman II and Minuteman III ICBM weapon systems have a history of software modifications. Recent examples are:

a. In the mid-1970s, Minuteman II communication system updates included software modifications.

b. Following hardware transitions, Minuteman II systems were updated in 1977-1979 with new Improved Launch Control System (ILCS) software.

c. In the mid-1970s, Minuteman III systems were updated with Command Data Buffer (CDB) and Hybrid Explicit (HE) software changes.

d. Software only changes to improve weapon system accuracy were added to Minuteman III systems in 1978.

e. Minuteman II software changes as part of an Air Force Logistics Command (AFLC) effort, Accuracy, Reliability, and Supportability Improvement Program (ARSIP), are scheduled for 1986.

f. Minuteman III software changes for ARSIP are scheduled for 1988.

These changes affect a number of software programs including executive, [illegible], code processing, guidance, and targeting programs. The major efforts [illegible] mid-1970s have been to improve weapon system functions by only modifying software programs.

PEACEKEEPER PROGRAM MANAGEMENT [illegible]

Program and requirements [illegible] weapon system acquisitions. As an example [illegible] (PMD) for the Peacekeeper weapon system [illegible]

a. PMD R-Q [illegible], dated [illegible] the system and directed [illegible] ating bases.

b. PMD R-M 0075, dated Aug 1980, [illegible] Development; added [illegible] Talks (SALT) constraints, [illegible] gy sources and post attack [illegible] and discussed Environmental Impact Statement requirements.

c. PMD R-M 0075(2), dated Sep 1980, clarified budget [illegible] ments and changed two milestone schedule dates.

d. PMD R-M 0075([illegible]), dated Feb 1991, deleted missile [illegible] tor.

e. PMD R-M 0075(5), dated Aug 1981, updated the [illegible] Launch Control Center (ALCC) baseline and directed [illegible] determine life cycle logistics supportability.

f. PMD R-M 0075(7), dated Jan 198[illegible], [illegible] Peacekeeper missiles in existing [illegible] with [illegible] long-term basing modes. Directed studies [illegible] Continuous Patrol Aircraft, Ballistic Missile Defense, [illegible] ening.

g. PMD R-M 0075(8), dated Mar 1992, provided further guidance [illegible] Deep Basing studies.

h. PMD R-M 0075(9), dated May 1982, provided further guidance [illegible] Continuous Patrol Aircraft and updated program funding.

i. PMD R-M 0075(10), dated Jun 1982, provided guidance on [illegible] studies.

j. PMD R-M 0075(11), dated Jun 1992, provided further guidance [illegible] basing studies and program review reporting.

k. PMD R-M 0075(12), undated, implemented decisions to base 100 Peacekeeper missiles in existing Minuteman silos and directed additional basing studies to include the small missle.

l. PMD R-M 0075(13), dated Sep 1983, initiated Peacekeeper missile production and directed engineering design and demonstration for small, single warhead missiles, hard missile silos, and deep basing.

m. PMD 0075(14), dated Sep 1983, directed design, development, and test of a common ALCC capability for Peacekeeper and Minuteman.

n. PMD 0075(15), dated Oct 1984, updated program funding.

o. PMD 0075(16), undated, provided further guidance on the common ALCC capability and updated program funding.

Appendix C

MINUTEMAN SOFTWARE ERROR ANALYSIS

Both a developing contractor and a second, independent contractor analyze Minuteman software programs. This approach is very successful in finding systems that work properly. Throughout the development these two contractors find errors in requirements, design, and code. These errors or anomalies are resolved with no change, deferred changes, or a change to the software. The following summary is from anomalies reported by an independent contractor:

a. 574 anomalies on two projects, each with three software programs, were reported;

b. 171 of the anomalies were reported against requirements; 398 against design/code;

c. Requirements anomalies were reported both before and after coding; and

d. Design and code anomalies were reported during the coding phase (61:--).

These examples indicate that even in highly disciplined, well-defined programs, anomalies (errors) always occur.

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